Coastal Engineering Technical Note

IMPORTANCE OF DIRECTIONAL SPREADING OF WAVES IN THE NEARSHORE REGION

PURPOSE: To illustrate the importance of directional spreading in selection of design wave heights in the nearshore region.

INTRODUCTION: Historically, monochromatic (regular) or unidirectional spectral (irregular) waves have been used in hydraulic models of coastal projects. However, real ocean waves are short-crested, having directional spreading which spreads or diffuses wave energy over many directions about a central angle of wave approach. Based on over 1000 samples of ambient and storm conditions off the North Carolina coast measured with a linear gage array, Long (1989) and Long and Oltman-Shay (1989) found a complete absence of unidirectional waves. In fact, typical directional spreading was 20° to 40°. Sand et al. (1983) measured diffracted wave energy in the lee of an entrance breakwater for unidirectional and directional irregular waves. They found larger waves for the directional cases. Kirkegaard et al. (1980) measured motions of a moored vessel near an open jetty, and found differences in response between unidirectional and directional irregular cases. During harbor modeling tests, Bowers (1987) observed significantly reduced long-period energy in the harbor when directional spreading was present. Thus, the inclusion of directional spreading can have a significant effect on the design of coastal facilities and breakwaters.

Two examples are presented to illustrate the importance of wave directional spreading. The first case study describes the effect a submerged mound of dredged material has on wave heights in the lee of the mound. The second case study discusses the effect of directional spreading on transformed wave heights just offshore of the north entrance jetty at Yaquina Bay, OR.

SUBMERGED MOUND STUDY: The Corps annually spends millions of dollars on dredging and dredged material disposal. Prior to placing a submerged mound, it is important to determine the stability of the mound and its effects on the wave climate. Waves passing over a submerged mound are refracted and diffracted by the change in depth. Refraction and diffraction of waves passing over complicated bathymetry has long been an important consideration in Corps design. Although the complexity of natural sea states has been recognized, most engineering analyses of this phenomenon have been based on simplification of the sea state to a monochromatic wave with the assumption that this is a conservative representation. The propagation problem is solved either empirically with physical models or numerically by linear and nonlinear models. Although monochromatic numerical models have been fairly successful, spectral models are still in the developmental stage. The directional spectral wave generator (DSWG) was used in a laboratory experiment to generate realistic sea states for

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evaluating the monochromatic assumption and creating an extensive database for use in expanding the capabilities of existing numerical models.

A submerged mound with an elliptical shape (Vincent and Briggs, 1989) was constructed in the model basin. It had a major radius of 13 ft and a minor radius of 10 ft at the base with a height of 1 ft at the center (Figure 1). The water depth was 1.5 ft, giving a depth of submersion of 0.5 ft at the center. Water surface elevation time histories were measured in a 20 ft by 50 ft area. A 20-ft long array of nine resistance gages, spaced 2.5 ft apart, were placed in an aluminum frame to minimize the amount of interference from support legs. This gage frame was moved between tests to nine transects or locations, 5 parallel to the DSWG and 4 perpendicular. The same test conditions were repeated at each gage transect. Two overhead cameras were used to record the wave transformation in the vicinity of the submerged mound.

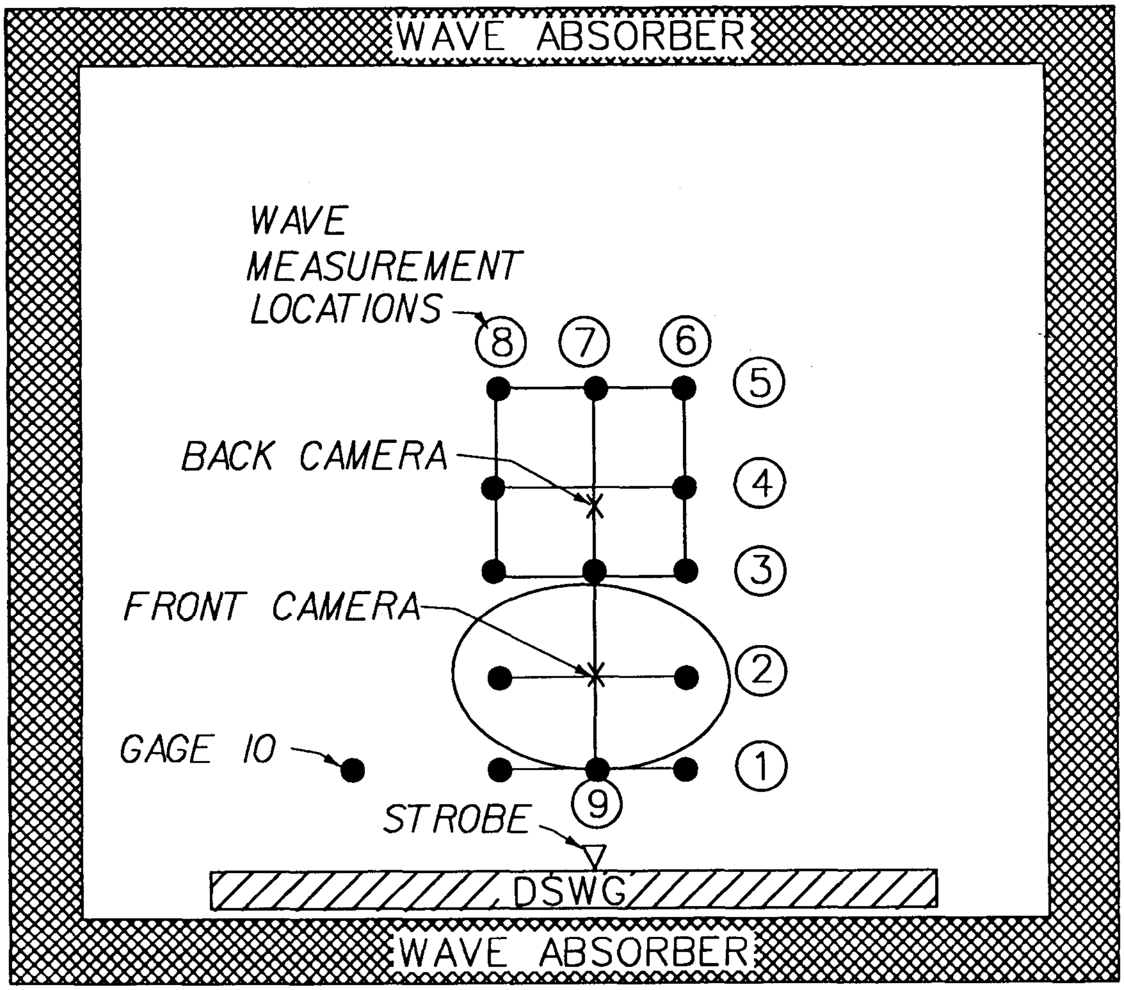

Figure 1. Location of submerged mound and measurement transects

The DSWG was used to generate monochromatic and unidirectional and directional irregular waves with equivalent wave periods and heights. The monochromatic wave period was equal to the spectral peak period. The monochromatic wave height was equal to 0.707 times the zero-moment wave height, H_{m0} (Thompson and Vincent, 1985). Irregular waves with both narrow and broad frequency and directional spreading were created. Figure 2 shows an example of the directional wave case with narrow frequency spreading and wide directional spreading. The rear vertical panels illustrate the integrated direction spectrum and frequency spectrum. The frequency spectrum is obtained by summing the directional spectrum over all directions for each frequency and multiplying by the direction increment. Similarly, the directional spectrum is the sum over all frequencies for constant direction, multiplied by the frequency increment.

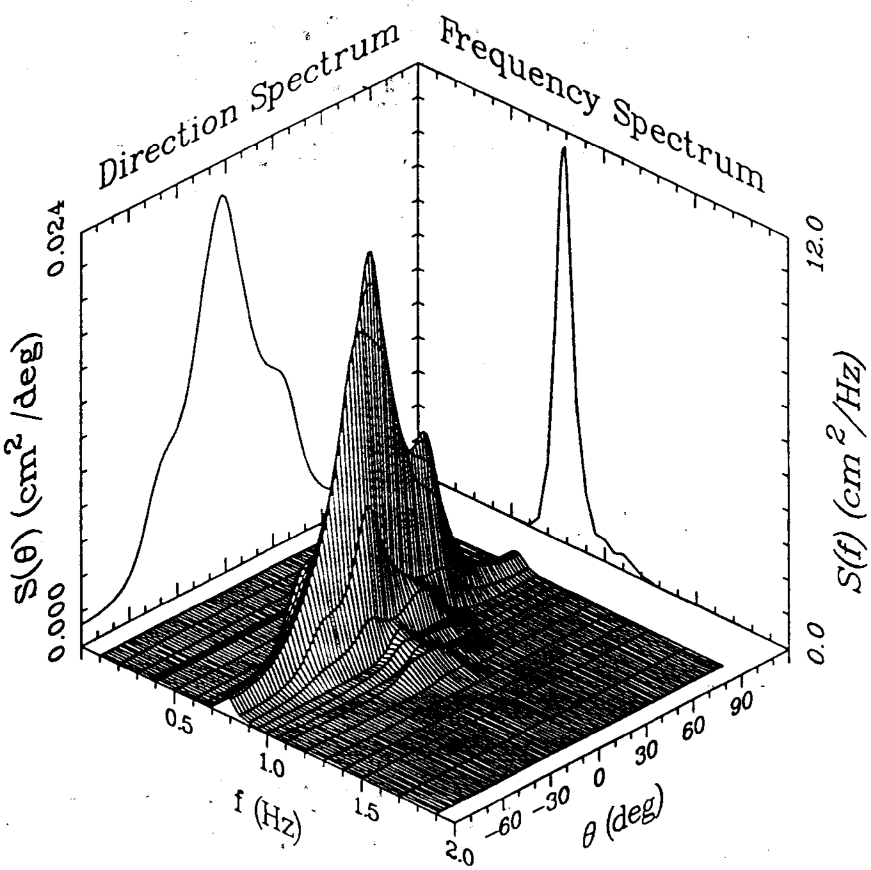

Figure 2. Directional spectrum with narrow frequency and wide directional spread

Figure 3 illustrates the wave transformation in the lee of the submerged mound for monochromatic waves. The waves are traveling across the mound (see outline of mound at the top of the picture) toward the bottom of the picture. For these waves the elliptical mound acts as a lens to focus wave energy, creating larger wave heights in the lee of the mound. The test results indicate that monochromatic waves deviate by as much as 50% to over 100% from irregular waves with typical spectral shapes and directional spreads.

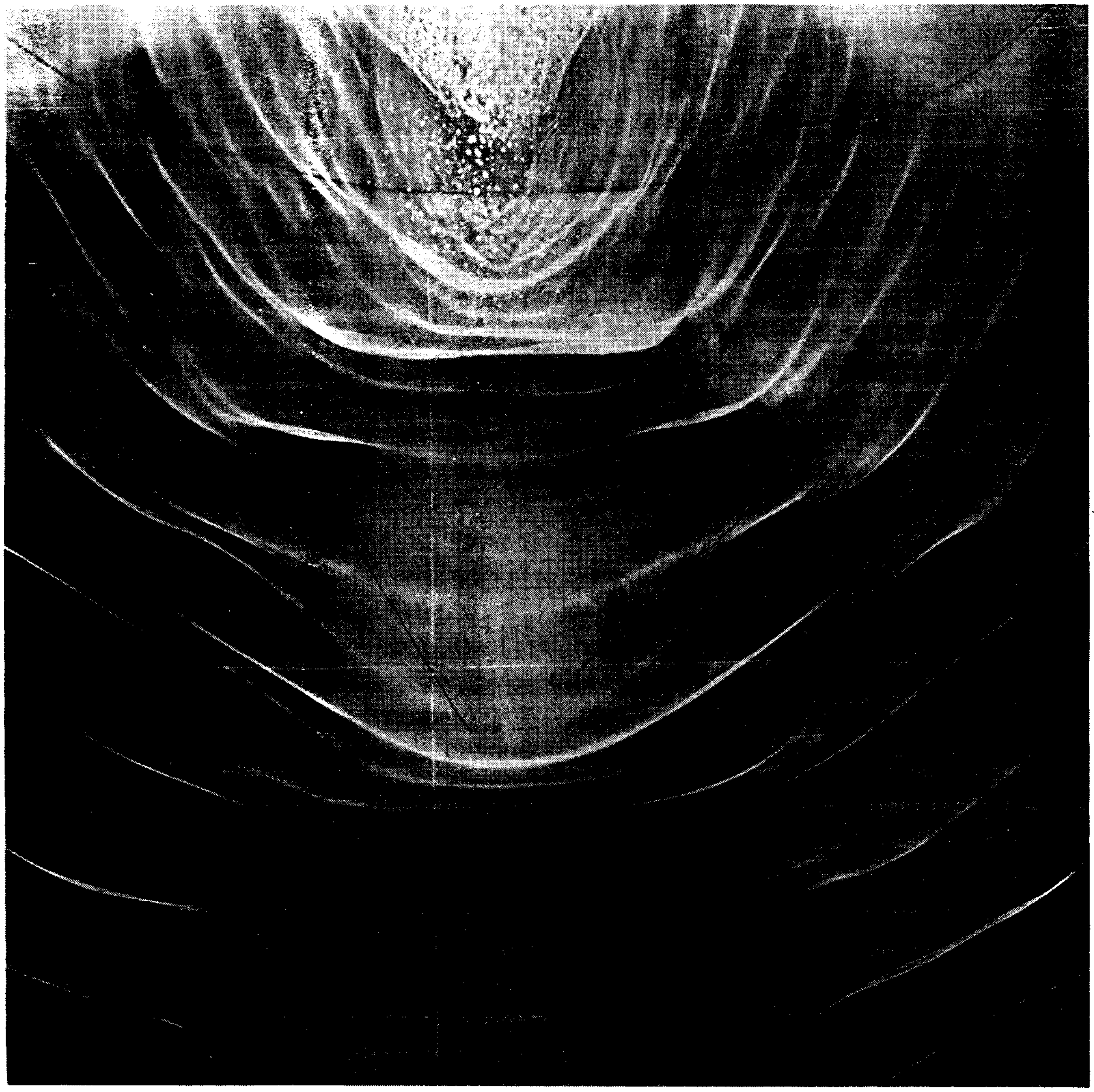

Figure 3. Wave transformation in the lee of the submerged mound

Figure 4 shows a comparison of the normalized (i.e. by incident wave height) wave heights along transect 4 for monochromatic, unidirectional, and directional irregular waves. Investigation of the cause of the difference included frequency and directional spreading in the spectrum, wave steepness effects, and wave breaking. Results indicated that monochromatic and even unidirectional irregular waves provide a poor prediction of wave conditions in the lee of a submerged mound if there is directional spread or high wave steepness. Thus, monochromatic and unidirectional irregular waves should be used with caution when estimating the wave environment in the lee of a submerged mound as both overpredict wave height.

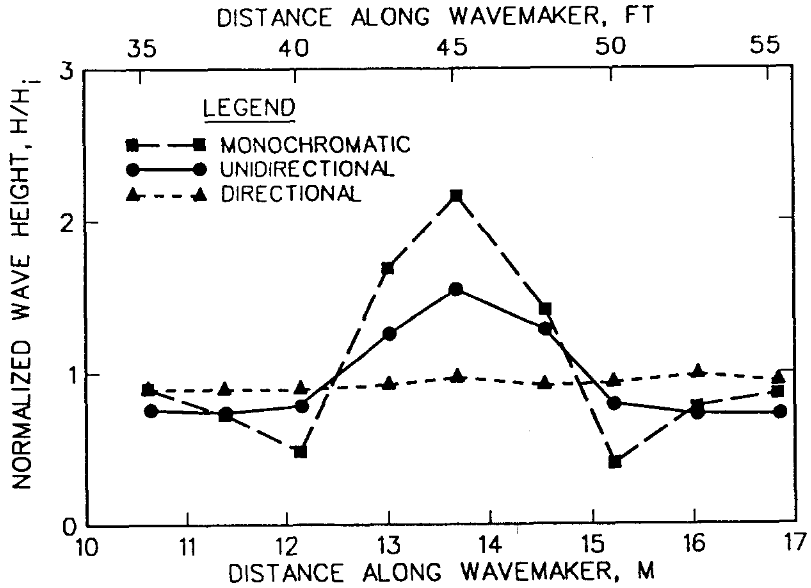

Figure 4. Normalized wave heights in lee of the submerged mound

YAQUINA BAY ENTRANCE JETTY STUDY: Yaquina Bay is an estuary located on the Oregon coast, approximately 110 mi south of the mouth of the Columbia River. Two rubblemound jetties protect the 40 ft deep, 400 ft wide entrance channel. This channel passes through an offshore basaltic reef, which lies approximately 3500 ft seaward of the channel entrance and extends northward for 17 mi.

The north jetty has been plagued with a history of unusually rapid deterioration when compared with similar North Pacific jetties. Since authorization of the jetty system in 1880, the north jetty has undergone extension or rehabilitation a total of seven times, the most recent in 1988 following damage in the period 1979 to 1980. Probable damage hypotheses are (a) wave breaking on the jetty, (b) wave-current interaction due to the presence of an offshore reef, (c) scour leading to armor unit slumping, (d) foundation failure, or (e) some combination of the above. The proximity of the reef to the end of the north jetty appears to be an important factor in modifying waves and currents at this location, especially since little or no damage has occurred to the south jetty which has similar construction characteristics and wave exposure.

A physical model of the proposed north jetty reconstruction in 1988 were conducted in late 1987 to test the first hypothesis (Briggs, Grace and Jensen 1989). The 1:45 scale model included the entrance channel, rubblemound jetties, and nearshore bathymetric contours.

Wave heights were measured at 9 locations using capacitance wave gages (Figure 5). Gages 1 to 7 were used in a calibration phase to insure accurate reproduction of the target wave conditions. The last two gages were located on either side of the north jetty head to measure wave transformation. Gages 2 to 6 comprised a linear array patterned after the larger linear array design of Oltman-Shay at CERC's Field Research Facility (Crowson et al., 1988). The unit lag spacing of 2 ft was selected to optimize the frequency and directional resolution of the array for the 50 ft prototype contour.

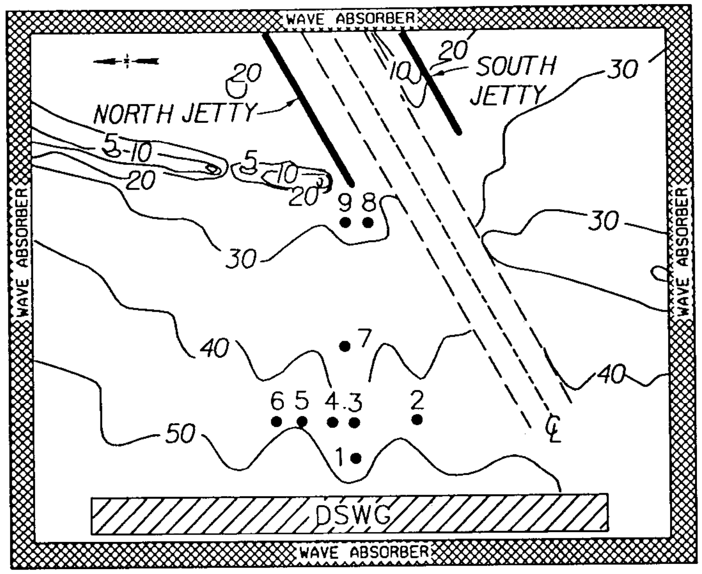

Figure 5. Experimental setup for Yaquina Bay, Oregon

A series of six storms, representative of the most severe storms in the past 20 years, were hindcasted by the Wave Information Study (Corson, et. al. 1987). They were multimodal in frequency and direction with locally generated wind sea and distant swell components. These deepwater storms were then refracted and shoaled (Hughes and Jensen, 1986) to the 58 ft depth contour, corresponding to the depth of the DSWG in the physical model. These storms had peak wave periods of 12.5 to 16.7 sec and significant wave heights of 14 to 22 ft. In addition, six energy-equivalent unidirectional storms (i.e. without directional spreading) were created from these directionally spread storms. The overall mean wave direction selected for these six unidirectional cases corresponded to the direction of the swell component of the six hindcasted, directional storms. Data were collected at two different water levels, one at MLLW and the other corresponding to a tide and storm surge of +10 ft, for the six directional and six unidirectional cases.

Figure 6 illustrates the influence of directional spreading on wave height transformation in the vicinity of the jetty. Measured wave heights from the two gages at the head of the north jetty were averaged and normalized by the corresponding incident wave height from the earlier calibration runs. A line connects the two water levels for each storm. Water levels corresponding to MLLW and storm tide and surge are marked "1" and "2", respectively. The 45° line is shown to indicate equivalence between unidirectional and directional heights. A value above the line implies that the directional height is larger than the corresponding unidirectional wave height. Conversely, a value below the line indicates the opposite relationship. Transformed wave heights were larger for the unidirectional storms relative to the corresponding directionally spread storms in all cases except for the 1970 storm. The average normalized wave height for the unidirectional cases was 0.83 and 0.94 for the two water levels, respectively. For the directional cases, this average increased from 0.75 to 0.87 due to the increase in water level. Thus, unidirectional irregular waves might lead to overly conservative estimates of transformed wave heights near coastal structures.

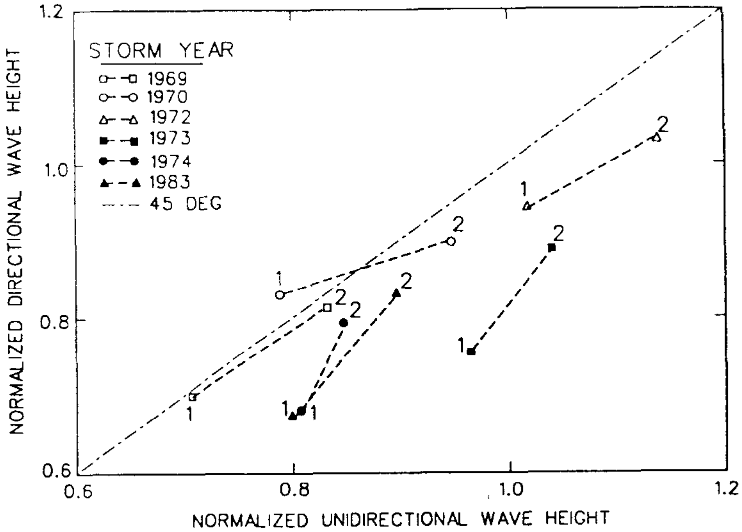

Figure 6. Wave height transformation for irregular waves

DISCUSSION: Two laboratory experimental studies have been described which demonstrate the effects of directional spreading on wave climate around a submerged mound and wave heights near an entrance jetty. In both cases, after interacting with an abrupt bottom change or coastal structure, monochromatic and unidirectional irregular waves were larger than irregular waves with directional spreading. Directional spreading is also important for studies of sediment transport, harbor response, breakwater diffraction, and wave-current interaction.

Historically, is has been impossible, or very expensive, to collect directional wave data in the field, simulate it in the laboratory, and model it numerically. CERC's new directional wave gage (DWG) makes it possible to collect directional wave data in the field more reliably and less expensively than in the past. Although still more expensive than unidirectional data, at least one of these gages should be used to collect nearshore directional wave data for every study. The DSWG has made it possible to reproduce realistic sea state directional characteristics in the laboratory. The DSWG is more expensive to use than traditional unidirectional wavemakers and is thus not economically justifiable for all laboratory investigations. However, where the study warrants it, the DSWG should be used to insure the most accurate reproduction of linear and nonlinear characteristics and transformation of waves. Inclusion of directional spectral characteristics in numerical models is still in the developmental stage. Part of the reason why these models have not developed more quickly is because their was very little field or laboratory data available to verify the numerical results. Now with more data becoming available, numerical modeling activity is increasing and improvements are appearing.

Coastal engineers should be aware that directional spreading can have an important effect on the design wave climate at coastal projects and include prototype data collection and laboratory studies in their project plans. Design wave heights can be overestimated if monochromatic or unidirectional waves are assumed. Future advances in numerical modeling of coasts and harbors will include the effects of directional spectra in ACES and other computer models.

The DSWG, in concert with the DWG, will continue to advance our understanding of the physics in nearshore coastal processes, while providing viable design alternatives for situations too complex for analysis using state-of-the-art numerical models.

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